Demo Abstract: Online QoS Adaptation using Fuzzy Control for Indoor Light Energy Harvesting in Wireless Sensor Networks

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***Abstract*—The bottleneck of long-term Wireless Sensor Network (WSN) applications is typically the energy. A promising solution is to enable each node to harvest energy directly in its environment, using individual energy harvesters. In energy harvesting WSNs, an important issue is the online adaptation of the node power consumption to avoid power failures while maintaining a good quality of service. This management is implemented on each node by an Energy Manager (EM). In this demonstration, Fuzzyman, a novel EM relying on fuzzy control theory, is applied to indoor light energy harvesting. The online adaptation of Fuzzyman is shown in terms of packet rate generation.**

I. Introduction

Traditional Wireless Sensor Networks (WSNs) are powered by individual batteries and a significant effort was devoted to maximizing the lifetime of these networks. However, as the batteries can only store a finite amount of energy, the network is still doomed to die, and changing the batteries is not always possible if the network is dense or deployed in a harsh environment. A more viable solution is to enable each node to directly harvest energy in its environment using individual energy harvesters.

As most of the energy sources are dynamic and uncontrolled, avoiding power failures of the nodes is critical to enable reliable networks. Nodes must therefore adapt their power consumption to the available energy and to their stored energy. This online adaptation policy is implemented on each node by an Energy Manager (EM). Designing a EM is challenging because the harvested energy is time varying and the amount of energy that will be harvested in the future is hard to predict.

Fuzzy control theory aims to extend the existing conventional control system techniques for a class of ill-modelled systems, *i.e.* fuzzy systems [1]. Because of the unstable and hard to predict behaviour of the harvested energy, EH-nodes are usually hard-to-model systems. Therefore, fuzzy control theory constitutes an appropriate framework to design EM for EH-nodes. Accordingly, we proposed Fuzzyman in [2], a EM for EH-nodes that relies on fuzzy control theory.

In this demonstration, we propose to show the enhancement of fuzzy control energy management designed for indoor light Energy-Harvesting WSNs (EH-WSNs). Fuzzyman is implemented on a real EH-WSN platform, its behaviour is shown by pointing out the evolution of the fuzzy sets according to the harvested energy, and the adaptation of the packet generation rate shows the online management.

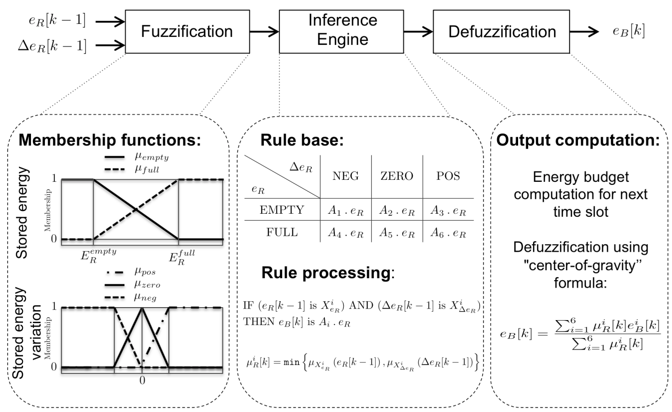

Fig. 1: Fuzzy logic controller for indoor light energy management.

II. Fuzzyman energy manager

A. Introduction of Fuzzyman

This section briefly introduces the different steps of Fuzzyman. The goal of Fuzzyman is to compute the energy budget that EH-node should use during a future period according to the residual energy of the battery at the end of the previous period. As a fuzzy logic controller [1], Fuzzyman is made of three units: the fuzzification unit, the inference engine, and the defuzzification. The fuzzification module aims to transform the physical inputs into fuzzy sets compatible with the inference engine. A fuzzy set consists of an interval for the range of the input value, and an associate normalized membership function describing the degree of the confidence of the input belonging to this range. The inference engine is the core of the controller. It is responsible for creating the control actions in fuzzy terms according to a rule base. Finally, the defuzzification unit maps the controller outputs to an energy budget that can be accepted by the node.

B. Fuzzyman for indoor light source

Fig. 1 shows the fuzzy logic controller used by Fuzzyman when being tuned for indoor light energy management. The two physical inputs are the stored energy e_R (*i.e.* the state-of-charge of the energy storage device) and the variation of

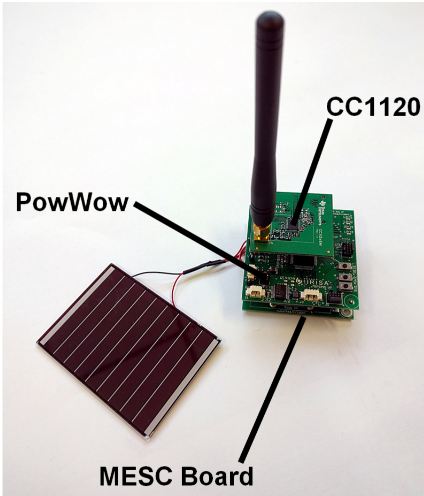

Fig. 2: PowWow platform used for demonstration equipped with a photovoltaic cell.

this energy between the two last executions of the EM. To describe the stored energy physical value, two fuzzy sets named "FULL" and "EMPTY" are considered. For the stored energy variation, three fuzzy sets, named "NEG", "ZERO" and "POS" are defined. The membership functions for these sets are displayed in Fig. 1. The task of the inference engine is to create the control actions in fuzzy terms from the inputs provided by the fuzzification module. The inference engine strategy is described by a set of six fuzzy IF-THEN rules shown by the table of the figure. Each rule consists in computing an energy budget $E_B^i = A_i.e_R$, $i = 1, \dots 6$. The coefficients A_i are set according to energy range of the harvested source and the energy storage size. Finally, defuzzification unit computes a physical value of the energy budget from the six outputs of the inference engine. The "center-of-gravity" scheme is used, which is the most common formula to perform defuzzifcation. A packet generation rate is then computed according to this energy budget.

III. Testbed and Demonstration

The platform PowWow [3] developed by the IRISA laboratory is used for the demonstration. PowWow node embeds the MESC architecture for energy harvesting and the Texas Instruments CC1120 radio chip for communication. The energy storage device is a super-capacitor with a maximum voltage of 5.2 V and a failure voltage of 2.8 V. The EH-node is equipped by a 38cm^2 photovoltaic cell and is powered using indoor light energy source. The so-obtained platform is shown by Fig. 2.

Fig. 3 shows the testbed that will be used for demonstration. It consists in a point-to-point communication between an EH-node and a sink that receives data from the EH-node. The EH-node embeds Fuzzyman to adapt its packet rate generation according to the harvested energy. The receiver being always switch on, packets are directly send to the sink once generated. A specific GUI has been designed to display the main results. Fig. 4 shows a screenshot of the interface. It shows at run-time the residual energy of the storage device, the wake-up interval

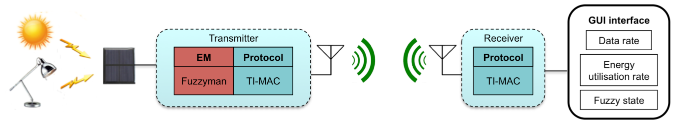

Fig. 3: Demonstration tesbed showing Fuzzy control energy management enhancement.

between two transmitted packets (directly linked to the packet generation rate) and the temperature as sensed data. Specific to Fuzzyman, the membership functions of the fuzzy sets are shown.

IV. Conclusion

This document presents a demonstration showing the behavior of Fuzzyman, an energy manager for energy harvesting wireless sensor networks. Fuzzyman relies on fuzzy control theory to deal with dynamic and uncontrolled energy sources. Including other model-free energy managers e.g. RLman [4] and other protocols leveraging wake-up radio [5] are future works for the development of this demonstration.

References

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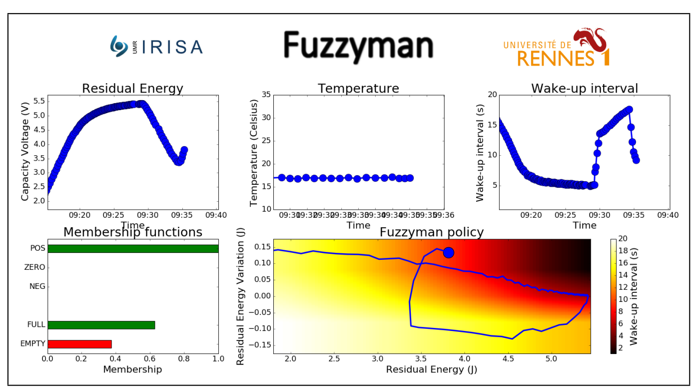

Fig. 4: Overview of the demonstration GUI.